THE PHOTOGRAPHY OF DISTURBANCES IN AIR.

In a paper read before the Royal Philosophical Society of Glasgow on December 4, 1901, and published in the *Proceedings* of the Society, Mr. H. S. Allen, of the Blythswood Laboratory, gives an account of "The Photography of Sound Waves and other Disturbances in Air." The method of striæ (Schlieren Methode) was devised by Toepler more than thirty years ago. This method makes it possible by suitable optical arrangements to render visible disturbances in which the refractive index differs but little from that of air.

One form of these arrangements is shown in the diagram, Fig. 1. The light proceeds from a source L which is as nearly as possible a straight line. In the figure this line of light is seen only in section—it is supposed to be at right angles to the plane of the paper. The light issuing from this source falls on a large concave mirror, M, by which it is brought to a focus just in front of the lens of the camera at I. One half of the lens is covered with an opaque screen, having a straight edge parallel to the image of the source, and the apparatus is arranged so that the image falls exactly on this straight edge Then, if all the adjustments are ideally perfect, no light at all will enter the camera so long as the medium through which the light passes is homogeneous. But supposing there is a region in the path of the light having a density different from that of the surrounding atmosphere, some of the light may be bent aside so as to enter the lens of the camera. Such a region is represented in section by the circle in the figure. It is supposed to be of greater density than the air around. The paths of the rays which have been refracted in passing through it are represented by the dotted lines. It will be seen that light traversing the lower portion is bent upwards and enters the camera, while light passing through the upper portion is bent downwards and falls still further than before from the boundary of the opaque screen. If the camera is focussed on this region of greater density, the lower part (that

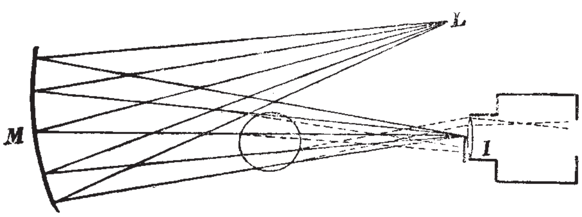

Fig 1.

is the upper in the camera, the image being reversed) will be illuminated, while the upper portion remains dark.

In working the method, the source of light and its image on the diaphragm must necessarily be of finite width, and the adjustments are made so that a certain fraction of the width of the image falls on the screen while the light from the remaining portion passes through the lens and gives rise to a uniform field. In these circumstances, the upper part of the region of greater density would appear dark against a light field. The sensitiveness of the method depends on the relative proportion of the light stopped by the screen and the light that enters the lens. For photographic purposes there must be a moderate amount of light to produce any effect even with the most sensitive plates, so that eye observations are considerably more sensitive. When it is desired to view the disturbances directly the camera is replaced by a telescope, or the image formed by the camera lens is examined by a suitable eyepiece.[1]

The mirror used was originally designed for a reflecting telescope. Its diameter was 18 inches, and it had a radius of curvature of 30 feet 3 inches.

One of the most striking applications of the method is the photography of sound waves—waves of compression set up by sudden electric discharges. Prof. R. W. Wood has taken a large number of photographs showing the behaviour of these waves (*Phil. Mag.* xlviii. p. 218, l. p. 148).

The arrangement of the apparatus is shown in Fig. 2. At the lower part of the diagram are the terminals, which supply an electric current at a high potential. The source of the current

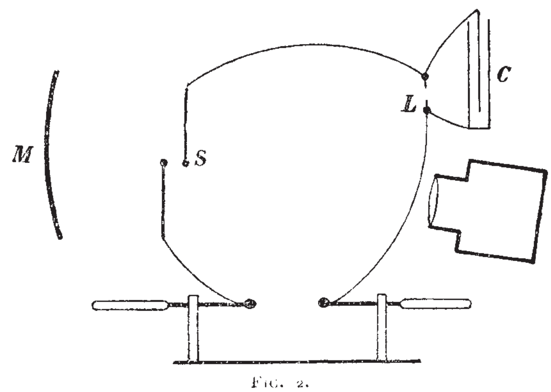

Fig. 2.

may be either an induction coil or an influence machine. From one terminal a wire is led to the spark gap placed in the path of the light travelling from the mirror to the camera. It is this spark which gives rise to the wave of compression to be observed, for convenience it may be termed the sound spark. The terminals are brass balls $\frac{5}{8}$ inch in diameter, and they are placed one behind the other, so that the light from the spark may not enter the camera. From this spark gap a wire is led to a second, which serves as the source of illumination, and is therefore provided with magnesium terminals. The circuit is completed by a wire from this point to the second terminal of the electrical machine. It is necessary that the light spark should take place somewhat later than the sound spark, in order to give the sound wave time to travel a sufficient distance from the terminals to be observed. To effect this a condenser is placed in parallel with the light spark, so that the light spark is delayed by the time necessary to raise the potential of the condenser high enough to spark across the gap.

A number of photographs were taken illustrating the reflection of a sound wave at surfaces of various forms and the effect of a diffraction grating. The original negatives were $\frac{1}{8}$ inch in diameter. They were enlarged to about three times this diameter for use as lantern slides.

The compression in one of these waves must be considerable compared with that due to an ordinary musical note. We may, perhaps, form a rough estimate of the amount of compression from the fact that the wave-fronts are seen at least as clearly as

Fig. 3.

the jets of carbonic acid gas which are described later. The refractive index of carbon dioxide is 1·000454, while that of air is 1·000294. Let us assume that the density of the compressed air is the same as that of carbon dioxide. According to the law of Gladstone and Dale, the ratio of the densities is the same as the ratio of the refractive indices less unity, that is, in this

[1] A somewhat curious effect is observed with the optical arrangements just described which might form the basis of an optical illusion. If the eye is placed close behind the back of the camera (the ground glass screen being removed), the source of light with the apparatus for producing the light is distinctly seen, but when an eyepiece focussed on the back of the camera is employed, the apparatus for producing the disturbances in the air is seen with the mirror as a background. In the former case, the eye sees the real image of the source just in front of the lens and so close to it as to be practically unaffected by it, while the image which can be seen with the aid of the eyepiece is so near the eye as to be invisible.

case the ratio of 454 to 294, or, roughly, of 3 to 2. Thus, with these assumptions, the density in the wave-front is half as great again as the density of the undisturbed air. The wave resembles that caused by an explosion rather than that due to an ordinary sound.

Several attempts were made to see the train of waves due to a musical note, but on consideration of the facts just stated it is not surprising that they were all unsuccessful. The notes due to a shrill whistle and to a siren blown by a pair of foot bellows were both ineffective.

An attempt was also made to obtain a train of waves from the oscillatory discharge of a condenser through a circuit possessing

FIG. 4.

self-induction. A large Leyden jar and a coil of wire were inserted between the main terminals in Fig. 2. The frequency of the oscillation lay between the limits 7920 and 1800 vibrations per second, the wave-length of the corresponding sound-wave lying between 1·3 and 7·3 inches.

A number of photographs were obtained in which the first wave-front had travelled to such a distance that the second wave should have been clear of the terminals. But in none of them is any trace to be seen of a second wave. Thus, as an attempt to photograph a train of waves, this method too proved a failure.

Even as a failure the result is not without its interest, as it brings out very clearly the difference in character between the first discharge and the surgings that follow it when the spark is an oscillatory one.

In the words of Prof. Trowbridge, who has made a special study of oscillatory discharges:—"Photographs of powerful

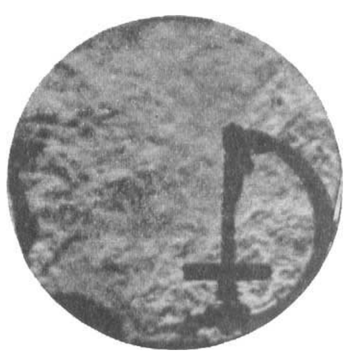

FIG. 5.

electric sparks lead one to conclude that a discharge of lightning makes way for its oscillations by first breaking down the resistance of the air by a disruptive pilot spark—through the hole thus made in the air the subsequent surgings or oscillations take place."

In the language of the modern ionic theory this would be interpreted by saying that the first disruptive discharge results in the production of a large number of free ions, and these ions offer an easy passage to the subsequent oscillations.

Since the refractive power of a gas is proportional to its density, and that in turn depends on the temperature, the method will reveal the presence of any region in the air whose temperature differs materially from that of the surrounding atmosphere. Such a case arises in every flame; the products of combustion rise from the flame as a column of heated gas, and this is revealed to the eye as a pillar of fire, or in the photograph as a pillar of cloud. The photograph shows the effect due to the flame of a spirit lamp (Fig. 3).

In order to impress the fact that what is here seen is not the flame, but the heated gas rising from the flame, a small fan was arranged which could be set in rapid rotation and so drive the hot gas all over the field of view (Fig. 4). The photograph (Fig. 5) shows the effect when it has been set rotating.

The flame of a Bunsen burner gives rise to a disturbance similar to that due to the spirit lamp, but more voluminous in character. The peculiar spiral form in which the column of gas rises before breaking up into a cloud is very noticeable in some of these photographs of flames.

A number of photographs were taken of jets of gas issuing from a narrow orifice. In one case the jet is formed by blowing heated air through a brass tube; in another it consists of carbonic acid gas issuing from the generating flask. In consequence of its great density, the gas begins to fall downwards soon after leaving the nozzle.

Several photographs were taken to show the mode of formation of a vortex ring of heated air. These rings were produced in the usual way by means of a box with an aperture in one side, and the opposite side formed of some elastic material. On giving this side a sharp tap, some of the enclosed air rushes out with the formation of a ring. In this case the air in the box was heated by placing a spirit lamp inside it so that the rings,

FIG. 6.

being formed of hot air instead of smoke, were quite invisible save by the use of the method of striæ. Some of these photographs are reproduced in the paper and are very instructive as showing the way in which the vortex motion is produced. The air appears first of all to issue from the orifice in the form of a column, but the tail is gradually left behind while the whirlpool motion of the head is accentuated. Finally, little is to be seen but the section of the ring itself, the spiral structure being strongly marked (Fig. 6). In some cases a circular, in others an elliptic orifice was used.

The appearance of some of these photographs showing vortex motion strongly recalls the published photographs of the nebulæ of the heavens.

THE TEMPERATURE OF INVERSION OF THE JOULE-KELVIN EFFECT FOR HYDROGEN.[1]

IN the year 1854 it was proved by Joule and Lord Kelvin that hydrogen on free expansion behaved differently to all other gases. Air, when allowed to expand from a higher to a lower pressure without performing external work, became cooled, the fall of temperature being proportional to the difference of pressure; hydrogen, on the other hand, became warmer. As is well known, the Joule-Kelvin effect has been applied by Hampson and Linde to the liquefaction of air in quantity, but since for hydrogen the effect is of opposite sign, it was obvious that the Hampson-Linde apparatus could not be directly applied

[1] By K. Olszewski. Translated from the *Bulletin* de l'Académie des Sciences de Cracovie. (December, 1901.)